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MEDIO-LATERAL ACCELERATION OF FEMALE ATHLETES WITH AN ACL RECONSTRUCTION IN COMPARISON WITH A HEALTHY POPULATION

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We assessed change of direction abilities in team sport female athletes. Ten participants returned to full activity from ACL reconstruction (ACLR) for longer than one year and 10 healthy controls (CON) were compared. Twelve maximal effort 45° cutting manoeuvres from the reconstructed side (ACLR) or a random selection of both sides (CON) were analysed for each individual using a motion capture system. CON showed greater medio-lateral centre of mass (COM) acceleration between 51 and 75% of ground contact. CON reported increased ankle plantar flexor power from 94 to 98% of foot contact, with also a higher peak. Although cleared to return to full activity, biomechanical differences associated with performance were still present in the ACLR group, which may have implications for better targeting rehabilitation practice.

KEYWORDS: sidestep cutting, performance, injury, return to sport, statistical parametric mapping.

INTRODUCTION: Anterior cruciate ligament (ACL) ruptures are some of the most serious sports injuries affecting the knee, and are particularly prevalent in sports where jumping and sudden changes of direction, e.g. sidestep cutting manoeuvres, are common. Successful performance in multidirectional sports is often linked with a player's ability to change direction and to accelerate (Buckthorpe, 2019), often leading to decisive actions, e.g. evading an opponent or generating space. Thus, following ACL reconstruction (ACLR), a lower ability to impart acceleration when pushing off the reconstructed limb may disadvantage players' performance and a fully successful return to activity.

Sankey et al. (2020) quantified acceleration during sidestep cutting manoeuvres in a healthy group, and found an acceleration of 4.91 ms^{-2} in a 45° sidestep cutting task. However, their study did not assess the behaviour of athletes returned to full practice after ACL reconstruction. Emerging studies on the kinematic determinants of acceleration in linear sprinting have consistently found shorter ground contact times to be related to better acceleration (Murphy et al., 2003) and for these shorter ground contact times to be associated with faster times to complete a sidestep cutting manoeuvre (Marshall et al., 2014). Thus, it appears that shorter ground contact times are also likely important for explaining performance in sidestep cutting manoeuvres. Completion times of sidestep cutting manoeuvres have been associated with larger peak ankle power (Marshall et al., 2014) for cuts to angles of 75°. Marshall et al. (2014) also reported concentric ankle power to be the strongest predictor of cutting performance.

As change of direction ability and acceleration are key aspects of performance in multidirectional sports, restoring these capabilities after ACL reconstruction is an essential part of rehabilitation (Buckthorpe, 2019). However, one in three athletes do not return to their preinjury level of sport (Ardern, 2015) and some who return to sport suffer repeat injury relatively quickly, suggesting that current return-to-sport programmes may be not sufficient or intense enough to fully prepare the athlete for the demands of the sport and that deficits in neuromuscular performance and movement quality have not been identified and sufficiently resolved (Nagelli & Hewett, 2016). Thus, quantifying acceleration capabilities during a sidestep cutting manoeuvre and determining whether any differences exist between a healthy population and one which has cleared to return to sport after an ACL reconstruction would provide valuable information for informing the structure of rehabilitation.

The aims of the present study were two-fold: establish whether there is a difference in acceleration from kinematic sources between a healthy population and one which has undergone an ACL reconstruction when performing a sidestep cutting manoeuvre; and, assessing the biomechanical factors that have been shown to dictate acceleration.

METHODS: Twenty national and international-level female multidirectional sport athletes partook in the study after signing informed consent. The study was approved by the local ethics committee. Ten participants were at least one year post ACL reconstruction (ACLR; age: 24 ± 5 y, height: 1.74 ± 0.04 m, mass: 73.5 ± 9.4 kg, years after surgery: 5 ± 4), whereas the ten healthy participants had never experienced any major lower limb injury (CON; age: 23 ± 5 y, height: 1.71 ± 0.04 m, mass: 65.1 ± 5.8 kg).

After warming up (jogging and self-directed stretching) and familiarising with the task, participants performed 24 maximal effort 45° sidestep cutting manoeuvres in a randomised order, totalling 12 to the left and 12 to the right. A 12-camera motion capture system (Oqus 400, Qualysis AB, Sweden; 200 Hz) and a force plate (Kistler Instruments Ltd, Switzerland) simultaneously collected the kinematics of trunk and lower limbs (Vanrenterghem et al., 2010) and ground reaction forces. Twelve randomly selected trials from either limb (CON), or the 12 repetitions from the reconstructed ACL limb (ACLR) were used for analysis. Landmark trajectory, and kinetic data (in inverse dynamics), were low pass filtered (12 Hz low-pass zero-lag Butterworth) as per Stearns and Pollard (2013). Medio-lateral COM acceleration, ankle plantar flexor power and overall contact time were calculated from touchdown to toe-off using a 20 N threshold to identify first and last frame of contact. Ankle power was normalised to body mass. Data were processed using Visual 3D (v2020.08.3, C-Motion Inc., Rockville, MD, USA). One-dimensional quantities were time registered to 101 data points and Statistical Parametric Mapping (two-tailed t-test from the SPM1D package, $\alpha=0.05$; Pataky, 2012) was applied to compare curves from the healthy and ACLR groups. A Mann-Whitney U test was conducted to compare leg contact time. Cohen's d effect sizes were also calculated and interpreted using the methods of Cohen (1988) for peak medio-lateral acceleration, peak ankle plantar flexor power and ground contact time.

RESULTS: Maximum medio-lateral COM accelerations were 16.41 ± 1.62 ms^{-2} and 13.19 ± 1.63 ms^{-2} ($d = 1.98$) and were achieved at 61% and 62% of stance for the CON and ACLR groups, respectively (Figure 1a). SPM analysis revealed a greater medio-lateral acceleration for the CON group in comparison to the ACLR group from 51 to 75% of the plant leg contact time ($p < 0.001$).

Although Cohen's *d* returned a large effect towards greater plant leg ground contact times for the ACL reconstructed group, there was no clear evidence of differences between the healthy (0.187 ± 0.014 s) and ACL reconstructed (0.213 ± 0.033 s) groups ($p = 0.054$, $d = 1.03$).

Both groups experienced a period of power absorption in the first half of stance followed by a period of power generation for the remainder (Figure 1b). The transition to positive power occurred at 58% of stance for both groups. CON and ACLR exhibited very similar curve patterns, up until after the onset of power generation where the CON group produced more ankle plantar flexion power between 94 and 98% of plant leg contact ($p = 0.034$). Positive power peaked at 81 % and 80 % of stance for CON and ACLR groups, respectively. Peak power was 18.38 ± 4.38 W/kg for the healthy group and 14.45 ± 1.77 W/kg for the ACL reconstructed athletes ($d = 1.18$).

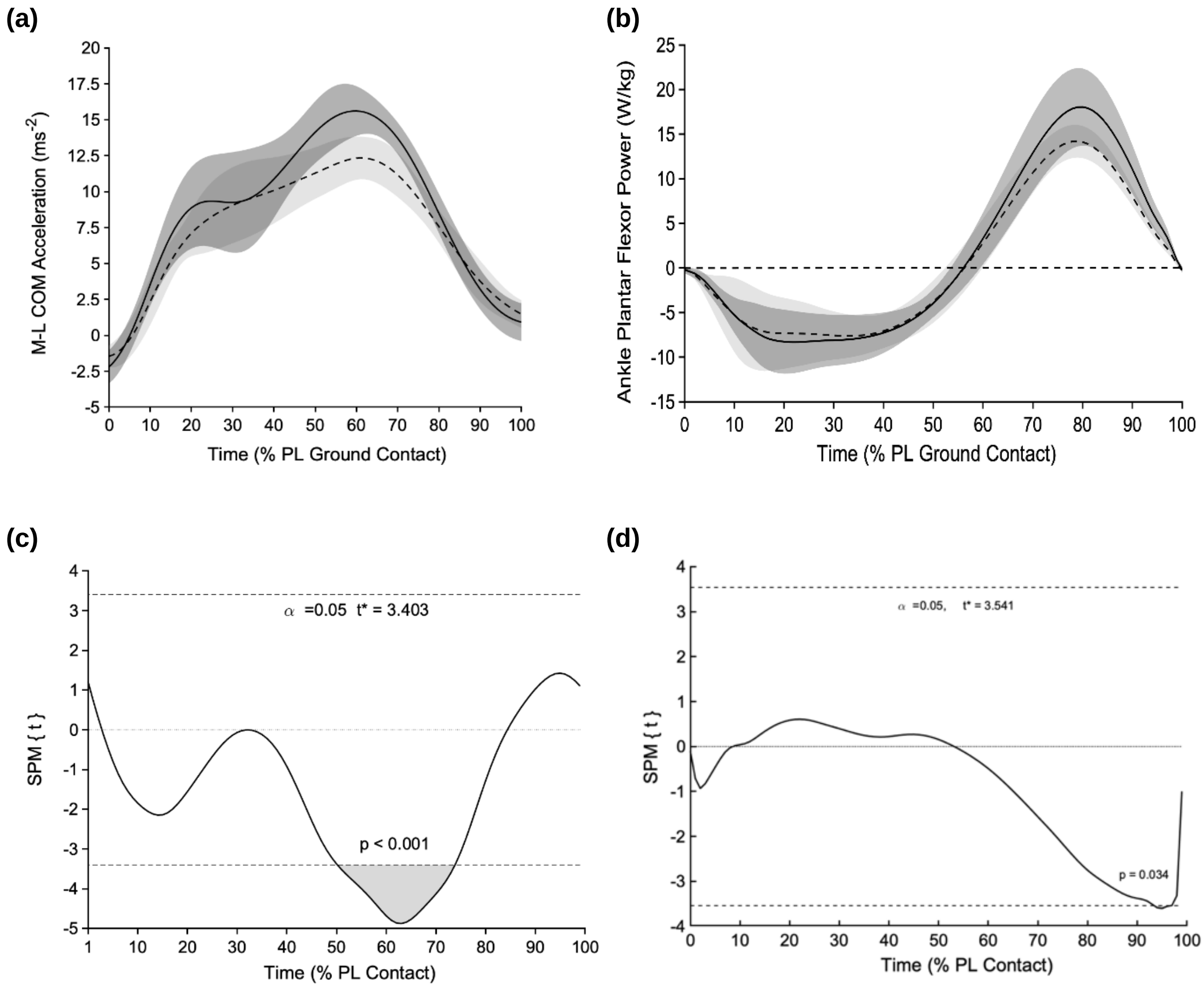

Figure 1. Ensemble averages (Mean ± SD) curve for the CON (solid line) and ACLR (dashed line) groups, from touchdown (0%) to toe-off (100%), expressed as a percentage of plant leg ground contact time. (a) Medio-lateral acceleration of the centre of mass (COM). (b) Ankle plantarflexor power, normalised to body mass. A positive value indicates power generation whereas a negative value indicates power absorption. (c) SPM{t} for medio-lateral acceleration of the COM. (d) SPM{t} for ankle plantarflexor power.

DISCUSSION: We compared performance-related kinematic and kinetic features between female athletes returned to full competitive activity after ACL reconstruction surgery and a control group that had not experienced any serious lower limb injury. A 45° sidestep cutting manoeuvre was assessed. All participants were team sport athletes of a high playing standard and at least one year had passed since they had been declared fully recovered. Hence, we hypothesized that no difference in movement performance would be expected between the two groups. The healthy group achieved greater medio-lateral acceleration during the third quarter of plant leg contact, and increased plantar flexion power in the final instants of ground contact, compared to the ACLR group.

Average medio-lateral acceleration of both the CON (8.64 ± 0.90 ms^{-2}) and ACLR (7.42 ± 0.88 ms^{-2}) groups was greater than the average of 4.91 ± 0.91 ms^{-2} reported by Sankey et al. (2020), which may be a reflection of the higher playing standard of and higher cutting angles achieved by the participants in our study. Plant leg ground contact time fell within the range of 0.157-0.280 s reported for 45° sidestep cutting manoeuvres (Sankey et al., 2020) but based on the large effect size provides an indication that these times may be shorter for the healthy group. The healthy group began to generate greater plantar flexion power (including larger effect sizes for peak power) in the final phase of plant leg ground contact. These differences occurred in the final push off phase (Besier et al., 2001), and, together with the other changes observed between the two groups, may reflect a performance deficit of the ACLR individuals

in completing the cutting task. Indeed, Marshall et al. (2014) identified ankle power as strongly associated with cutting time (explaining 59% of its variation), and suggested a focus on enhancing explosive force production at the ankle to aid in improving sidestep cutting performance.
In a study of drop jumps, plyometric exercises have previously been shown to result in shorter ground contact times and large ankle plantar flexor moments and powers (Marshall & Moran, 2013) and thus appear an appropriate strategy for improving the acceleration limiting factors identified in the present study. Plyometric exercises are currently implemented in the later stage of rehabilitation when there has been adequate time for healing of the ACL graft to move onto more dynamic exercises but given the reduced moment and powers reported presently the use of these exercises should perhaps be emphasised further.

CONCLUSION: Findings of the present study show that despite having been cleared to return to sport, athletes with an ACL reconstruction were not able to produce the same medio-lateral acceleration as healthy athletes when performing 45° sidestep cutting manoeuvres. Furthermore, the ACLR group demonstrated reduced ankle plantar flexor power and a tendency towards longer contact times, both of which may contribute to the reduced lateral acceleration. Results highlight that there may be a need for greater emphasis on components of rehabilitation to target these factors and reduce the difference between those with an ACLR and healthy populations.

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